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ABSTRACT: The present paper is an expansion of the study of the basic relationships between astrophysical phenomena and radiocarbon, as presented by the authors in [1]. Determination of the radiocarbon content in dendrochronologically dated samples is used to study solar cyclic activity, flares from supernovae, etc. In addition, the atmospheric C^{14} concentration can be used to determine the characteristic times for C^{14} dispersion into various reservoirs.

I. INTRODUCTION

The intensity of physical experimentation in space is increasing sharply with the development of satellite technology. Research in space is of purely scientific as well as practical interest. Naturally, such a division of interests is particularly arbitrary since, without a knowledge of the mechanisms of processes in space, (the scientific side of the question), we could not carry out manned space flights. At the same time, for a detailed study of various phenomena, we must perform our experiments with the participation of the crews of the spacecraft. Thus, the two sides of the question are interrelated and complement each other. /2*

It is well known that, from the point of view of the safety of the flights, a prediction of the condition of the Sun, which essentially determines conditions in the Earth's atmosphere and in the space around the Earth, has great significance. A knowledge of the characteristics of various processes on the Sun can allow us to predict the Sun's condition. For this purpose, we must necessarily investigate in detail, the energy spectrum and the intensity of both corpuscular and electromagnetic solar radiation; we must determine the behavior of the processes with time.

Existing research methods record events, from which signals are obtained at the time of the experiment, i.e., conforming to the Sun, and the processes which occur practically at the same moment of time are examined. At the same time, in order to examine the behavior of the processes with time, we must have data for a

* Numbers in the margin indicate pagination in the original text.

sufficiently long period of time. The length of the interval, naturally, depends on which phenomenon we are studying. If, for example, we are speaking of an 80-year cycle of solar activity, the length of the interval should be 100 years, etc. Knowledge of the Sun's condition for a long interval in the past can allow a prediction of its condition in the future. In connection with this, research in the methods of investigating the Sun's condition the atmosphere of the Earth, and the space around the Earth, is of interest. The necessity of finding "eyewitnesses" of the past does not arise only in connection with the study of the changes in the Sun's condition with time. The mechanism of the flares of supernovae, objects which are presently considered as sources of cosmic rays, is still unclear. The difficulty in examining the flares of supernovae is caused to a large degree by the fact that the sensitivity of contemporary methods of recording radiation (gamma and x-rays, neutrinos) does not permit studying flares from stars which are located in other galaxies. Whether or not there will be a flare in our galaxy in the near future is unknown. It is certainly well known that, in the last millenium, in our galaxy, flares occurred in at least three supernovae. The question naturally arises: did these flares leave a trace in the solar system, which would allow the characteristics of the flares to be determined? /3

In 1965, the authors of this paper [1] were concerned with the possibility of examining various astrophysical phenomena by determining the radiocarbon content in samples of known age.

This paper is dedicated to a development and more detailed examination of the basic findings in that article.

II. DISTRIBUTION OF C^{14} IN VARIOUS RESERVOIRS

The opinion that C^{14} is produced by the action of cosmic rays on the Earth's atmosphere is generally accepted. Neutrons of the secondary component of cosmic rays form radiocarbon by the reaction $N^{14}(n,p)C^{14}$.[1] Radiocarbon, like regular carbon, is oxidized and mixes with normal coarbon dioxide in the atmosphere. Plants absorb carbon dioxide from the atmosphere, and animals worlds contain radiocarbon. Atmospheric carbon dioxide also penetrates into the oceans as dissolved carbonate and bi-carbonate. Therefore, we can see that the ratio between the concentrations of radiocarbon and regular carbon is around 10^{-12} (in present-day organic substance, C^{12} = 98.9%, C^{13} = 1.1%, C^{14} = 10^{-10}%). If a sample is removed from the exchange cycle because of the death of an animal or plant, the decay of C^{14} is not compensated for by the assimilation of CO_2 /4

[1] Radiocarbon is also formed by the reactions $O^{16}(n,He^3)C^{14}$, $O^{17}(n,\alpha)C^{14}$, $N^{15}(n,d)C^{14}$, $C^{13}(n,\gamma)C^{14}$. However, we can easily show that the contribution of these reactions to the rate of C_{14} formation is negligibly small.

from the atmosphere and, thus, the concentration of radiocarbon decreases for the period of the half-life of C^{14}, which is equal to $T_{1/2} \simeq 5730$ years [2].

Therefore, experimental determination of the quantity of non-decaying atoms in a carboniferous material permits calculation of the time which has elapsed since the moment of the cessation of carbon exchange. The radiocarbon dating method [3], which won the discoverer of this method (Libby) the Nobel Peace Prize, is based on this fact. The method of radiocarbon dating is based on three assumptions:

(1) The intensity of cosmic rays and, thus, the rate of formation of radiocarbon in the Earth's atmosphere, is constant during several periods of the half-life of C^{14}.

(2) The percentage of radiocarbon in various reservoirs is constant during the same amount of time.

(3) The rate of transfer of C^{14} from the atmosphere to other reservoirs, particularly to the hydrosphere, is also constant.

By measuring the percentage of radiocarbon in samples with a known age, Libby and Anderson [3] showed that the specific activity of C^{14} is constant during several periods of half-life, with an accuracy of several percent. Moreover, the reliability of the dating method was shown, and a basis for wide-ranging research was provided.

With development of the techniques of measuring C^{14}, the existence of fluctuations in the concentration of radiocarbon in the Earth's atmosphere was discovered. In the last 100 years, the liberation of "old carbon", which does not contain C^{14}, into the atmosphere as a result of combustion of billions of tons of fossil fuel (petroleum, gas, coal) played a substantial role. Estimates showed that in the period of from 1860 to 1954 the amount of "old carbon" which was added to the atmosphere was about 13% of the normal percentage of carbon in the atmosphere. If dispersion among various reservoirs occurred instantaneously, the concentration of C^{14} in the atmosphere should vary by a total of 0.13% and the effect of rarefaction (Suess' effect) would not be known. Suess [4] showed that the C^{14} concentration actually decreased by 2% because of the combustion effect. Proceeding from these data, Fergusson [5] determined the average lifetime of a molecule of carbon dioxide in the Earth's atmosphere. It was less than 7 years. /5

Vries [6] was concerned with short-lived changes in C^{14} concentrations in samples of known age, dating from 1700 A.D. He assumed that these fluctuations were connected with climatic changes throughout the world, and he compared them with the advance and retreat of glaciers from the 17th century to the present time.

An analysis of the annual layers of wood, conducted on samples from trees which were accurately dated for the last 1300 years, showed substantial fluctuations in C^{14} percentage [7]. These fluctuations reflect the actual changes in C^{14} percentage in the carbon dioxide of the atmosphere.[2] Variations of radiation in space can be one of the more probable reasons for these changes. Variations in radiation in space occur as a result of the cyclic change in solar activity and, possibly, accompany such relatively rare phenomena as the flares of supernovae, etc.

In connection with this, we were interested [1] in the importance of correlating the C^{14} percentage in the annual rings of both live trees and those which have been archaeologically dated, with historically known astronomical phenomena or with data from comtemporary observers. This would permit us to determine the date of any catastrophic event in the past.

At the time when our article was published [1], there was very little experimental data on C^{14} concentrations in samples of known age. Subsequently, there appeared papers [8-11] which were dedicated to examining the percentage of radiocarbon in a great quantity of samples whose age was known.

Such a vigorous interest in determining the C^{14} concentration in dendrochronologically dated samples convinced us even more of the necessity of examining the question of the role of radiocarbon in astrophysical research.

The total amount of C^{14} in all the reservoirs, determined by the balance between the processes of decay and formation of C^{14}, is around 60 tons. The principal bulk (90%) of C^{14} is contained in the hydrosphere (basically in inorganic compounds), and the re- /6
maining amount is in the carbon dioxide of the atmosphere, in the biosphere of the Earth, and in humus. The total quantity of C^{14} in the Earth's atmosphere is $\sim$ 700 kg ($3 \cdot 10^{28}$ atoms). There is carbon exchange between reservoirs, and, on the average, there is dynamic equilibrium. If, for some reason, the C^{14} percentage varies in one of the reservoirs (in the atmosphere, for instance) then equilibrium will again be reestablished after some time. It is significant that the volume of the atmospheric reservoir is very small by comparison with the whole. This leads to the fact that even relatively great changes in the quantity of C^{14} result in a small change in the total amount of C^{14} in all the reservoirs taken together. In connection with this, it is very important to know

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[2] The yearly process of carbon assimilation in trees is connected with the formation of a new annual layer of wood. Each year, the growing layer is practically disconnected from the hydrocarbon exchange, and thus the C^{14} percentage in the annual layer corresponds to the C^{14} concentration in the atmosphere in the year of formation of that layer.

the dynamics of the radiocarbon exchange among the reservoirs.

In order to solve this problem, the corresponding balance equations for two reservoirs are usually constructed: for the atmosphere and for the hydrosphere[3] [10,12]:

$$\begin{aligned} \dot{X}_1(t) &= Q(t) - (\lambda + \lambda_1)X_1 + \lambda_2 X_2, \\ \dot{X}_2(t) &= \lambda_1 X_1 - (\lambda + \lambda_2)X_2 \end{aligned} \tag{1}$$

where the subscript 1 refers to the atmosphere and the subscript 2 refers to the hydrosphere; X is the quantity of C^{14} in $g \cdot cm^{-2}$; Q is the rate of C^{14} formation in $g \cdot cm^{-2}$ $years^{-1}$; $\lambda = 1/\tau$ $years^{-1}$ is the constant of C^{14} decay; λ_1 is the probability of transfer of C^{14} from the atmosphere to the hydrosphere in a unit time, λ_2 is the probability of transfer of C^{14} from the hydrosphere to the atmoshpere in a unit time.

We will examine two cases: (a) the amount of atmospheric radiocarbon varies instantaneously by the value ΔX_1 $g \cdot cm^{-2} \cdot (\Delta Q(t) = \Delta X_1 \delta(t))$. This case corresponds to explosive processes such as a thermonuclear blast or the flare of a supernova. (b) $\Delta Q(t) = |\Delta Q| e^{i\omega t}$. This case corresponds to cyclic processes. As an example, we can use the activity of the Sun. Let us introduce the following symbols: A_1 and A_2 are the amounts of C^{12} in $g \cdot cm^{-2}$ for the atmosphere and hydrosphere, respectively; $R_1 = \frac{X_1}{A_2}$ and $R_2 = \frac{X_2}{A_2}$ are the C^{14} concentrations relative to C^{12} in the atmosphere and in the hydrosphere; $\lambda^* = \lambda + \lambda_1 + \lambda_2$, Q_0 is the average rate of C^{14} formation in $g \cdot cm^{-2}$ $years^{-1}$. Using these symbols, a solution for Equation (1), Case (a), can take the form [13,14]: /7

$$\begin{aligned} \Delta R_1 &= \frac{\Delta X_1}{A_1(1+\nu)} \left(e^{-\lambda t} + \nu e^{-\lambda^* t}\right), \\ \Delta R_2 &= \frac{\Delta X_1}{A_1(1+\nu)} \left(e^{-\lambda t} - e^{-\lambda^* t}\right) \end{aligned} \tag{2}$$

[3] Naturally, for a more accurate solution for the problem, all the reservoirs should be considered. However, we will not do this for two reasons: first, not all the characteristic times for distribution among reservoirs are known; second, consideration of all the reservoirs only brings about an insignificant change in the results, which is practically insignificant in the basic conclusions.

where $\nu = \frac{A_2}{A_1} = \frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1}$, and T_2 is the average transfer time for C^{14} from the hydrosphere to the atmosphere. T_1 is the same value for the reverse process.

The presence of mixing layers in the oceans (intensive mixing extends to depths of ~ 75 m), generally speaking, makes it necessary to study three reservoirs: the atmosphere, the surface layers of the hydrosphere, and the subsurface layers of the latter. However, we can use (2), considering the surface layers either as a part of the atmospheric reservoir or as a part of the hydrospheric reservoir. In the first case, ν is equal to 30, and in the second case, it is equal to 60 (the amounts of C^{14} in the atmosphere and in the surface layers are approximately equal). The precise value for T_1 at the present time is unknown. According to the data we have, T_1 is within the interval from 6 to 30 years [12,13].

For case "b", solution (1) takes the form [13,14]:

$$\frac{\Delta R_1}{R_1} = F_1 \frac{|\Delta Q|}{Q_0}, \qquad \frac{\Delta R_2}{R_2} = F_2 \frac{|\Delta Q|}{Q_0}, \tag{3}$$

where

$$F_1 = \sqrt{\frac{1 + \left[\frac{(\nu+1)\tau T^*}{\tau + \nu T^*}\right]^2 \omega^2}{(1 + \tau^2\omega^2)(1 + T^{*2}\omega^2)}}$$

$$F_2 = \frac{1}{\sqrt{(1 + \tau^2\omega^2)(1 + T^{*2}\omega^2)}}$$

We shall use (2) and (3) subsequently in examining the problem of the change in radiocarbon concentration in the Earth's atmosphere, caused by the flare of a supernova and by the cyclic activity of the Sun. /8

III. Supernovae and Radiocarbon

At the present time, we know of 140 remnants of supernovae [15, 16]. Among them, in our galaxy, we have the supernovae of Cassiopeia A (1700), Kepler (1604), Tycho Brahe (1572), and the supernova in the Crab Nebula (1054). The supernovae can be divided into two types, I and II, by their properties.[4] The basic properties of supernovae, according to the data of [15-20], are shown in Table 1.

Supernovae of Type I flare with identical frequency in elliptic and spiral galaxies, concentrating in the domains of the galactic nuclei. Supernovae of Type II flare mainly in the arms of spiral galaxies.

A characteristic peculiarity of Type I supernovae is the complete similarity of curves of luminosity versus time. After a quick rise in intensity, and a flat maximum, there is a decrease by 2-3 stellar magnitudes in 20-30 days (Fig. 1) [20]. The luminosity then decreases exponentially with a half-life of 40-70 days. For Type II supernovae the shapes of the spectrum differ noticeably. They do have in common a relatively slow (in comparison to Type I supernovae) initial decrease.[5]

The existence of this exponential decrease was a basic hypothesis which indicated that release of energy from Type I supernovae is caused by spontaneous fission of such nuclei as Cf^{254} ($T_{1/2}$= 55 days) [21]. In this case, we can assume that the Cf^{254} nucleus is formed because of the "ch" process. In order to explain the observed luminosity of supernovae, we must have the formation of $\sim 10^{30}$g Cf^{254}.

Since the exponential decrease in luminosity for each supernova is characterized completely by the limited half-life, we should consider [21, 22] that each supernova owes its luminosity to the spontaneous fission of a given isotope. The latter assumption is definitely a weak link the "Cf^{254} hypothesis".

Colgate [20, 23, 24] considers that, when a degenerated neutrino nucleus is formed in a star, there is an outward reflection of the material which is falling toward the center of the star, as a result of which there is a shock wave. The wave intensifies in proportion to its distance from the center, since the density of the material decreases. As a result the velocity at the surface of the star becomes parabolic, and a part of the material is rejected into interstellar space. In this case, energy up to $\sim 10^{52}$ /10

[4]The TsVIKKI lists five types of supernovae [15].

[5]It is precisely because of this, regardless of any difference in luminosity, that the light energy emitted by supernovae of Types I and II is almost identical.

TABLE 1. CHARACTERISTICS OF SUPERNOVAE

Type	Photographic Stellar Magnitude at Maximum Luminosity (average)	Light Energy (erg)	Mass of the Supernova (M_0)	Mass of Discarded Shells (M_0)	Speed of the Shells (km/sec)	Kinetic Energy of the Shells (erg)	Presence of Hydrogen in the Shells	Stellar Population to which Supernova Belongs
I	-19.04 ± 0.23	$4 \cdot 10^{49}$	1.2-2	0.1-1	1000-2000	$10^{48}-4 \cdot 10^{49}$	-	Old Stars
II	-17.70 ± 0.34	$2 \cdot 10^{49}$	10	1-10	5000-10000	$2.5 \cdot 10^{50}-10^{52}$	+	Young Stars

erg can be liberated. In Colgate's model, in the outermost layers of the star, relativistic particles can be produced.

Finzi [25] recently showed the possibility of the energy release of a supernova being due to vibrational oscillations. Thus the vibrational energy can achieve values of $\sim 10^{52}$ erg [26].

Even a brief examination[6] showed that, at the present time, there is no single point of view on the question of the mechanism of flares from supernovae; this is basically due to the small quantity of experimental data.

In order to understand the physical nature of the phenomena which take place at the time of supernova flares, it is essential to know if γ-quanta emerge from the supernovae, and, if so, what their intensity and energy spectrum are.

In [1], we showed that a supernova flare in our galaxy should coincide with a significant change in radiocarbon concentration in the Earth's atmosphere, if the γ-luminosity of a supernova is not much less than its optical luminosity. In recent works by Clayton and Craddock [27], and in works by Gould and Burbidge [28], we find theories based on high γ-luminosity from supernovae.

If, during supernova flares, a large quantity of heavy nuclei, including radioactive ones, is formed by the "ch" process, then γ-quanta should be emitted. The sensitivity of modern γ-detectors does not presently allow recording γ-quanta from supernovae which flare in other galaxies. Therefore, the question naturally arises: what is the γ-radioactivity of the relics of supernovae in our /11
galaxy, due to nuclei which still have not completely disintegrated? Clayton and Craddock [27] examined the question of the γ-radioactivity of the Crab Nebula, proceeding from the correctness of the "Cf^{254} hypothesis". They showed that, of a full power of radioactive nuclei in the Crab Nebula equal to $\sim 1.2 \cdot 10^{36}$ erg/sec., only 1% is in the form of γ-quanta. The main part of the energy is given off as kinetic energy of α-particles and fission fragments. The strongest γ-line, belonging to Cf^{249}, has an energy of 390 keV. The flux of such γ-quanta on the Earth is $\sim 5 \cdot 10^{-5}$ cm^{-2}sec^{-1} [27]. A recording of this radiation is made difficult by the presence of the X-ray background of the Crab Nebula, which is a synchrotron and has a continuous spectrum. Use of apparatus with good angular and energetic characteristics will possibly allow finding a line of 390 keV. The importance of arranging experiments for recording γ-quanta with an energy of 390 keV is great, since the positive result would be direct proof of the hypothesis of the production of heavy nuclei by the "ch"-process at the time of supernova flares.

Gould and Burbridge [28] propose the following two mechanisms

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[6] For more detail, see [15].

for producing γ-quanta at the time of flares from supernovae.

1. Nuclear γ-rays, emitted in the process of nucleosynthesis.

2. γ-rays, emitted because of the interaction of relativistic particles with the magnetic field and with the material in the expanding shell of a star.

According to Gould and Burbridge, the flux of nuclear γ-rays ($E \sim 1$ MeV) at a distance of 1 kps from the supernova at the time of the flare (1 kps is the distance from the Crab Nebula to the Earth) is $\sim 10^4 \gamma\ cm^{-2} sec^{-1}$, and at a distance of 10 Mps (the distance from the Earth to extragalactic supernovae) is $10^{-4} \gamma cm^{-2} sec^{-1}$.

At the present time, the presence of a large quantity of relativistic electrons in relics of supernovae has been established. Thus we can see that generation of relativistic electrons in the Crab Nebula must still be going on at the present time, i.e. 900 years after the flare of the supernova. It has also been established that the electrons are primary and not secondary.[7] It is /12 natural to consider that the accelerator of the electrons is the former supernova and the relatively small domain surrounding it [15]. It is also natural to consider that a similar accelerating mechanism existed in the active stage of the supernova flare. The relativistic protons, accelerated at the time of the flare by interaction with the material in the star's shell, should form pi-mesons. Disintegration of charged pi-mesons produces neutrinos, electrons and positrons, and that of π^o-mesons produces γ-quanta. As a result, we can expect formation of a great quantity of γ-quanta. As a result, we can expect formation of a great quantity of γ-quanta with an energy of 50-100 MeV. Moreover, the interaction of electrons and positrons with thermal photons will also produce γ-quanta because of the reverse Compton effect.

As Gould and Burbridge [28] justifiably maintain, their concepts of the mechanism of generation of γ-quanta are to a great degree speculative, which emphasizes again the extremely unclear situation regarding the mechanism of flares from supernovae. At the same time, they imply the exceptional importance of the question of the possible generation of γ-quanta in the active stage of supernova flares.

Actually, a lack of γ-quanta of high energy would contradict the idea of generation of a great quantity of relativistic protons,

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7If the electrons had a secondary nature, then the positrons and γ-quanta should be produced together with them. Experiments by Chudakov and his collaborators [29] showed that the flux of γ-quanta with $E > 5 \cdot 10^{12}$ eV from the Crab Nebula is less than $5 \cdot 10^{-11}$ photons $cm^{-2} sec^{-1}$, i.e. more than 1000 times less than the secondary generation of relativistic electrons in the Crab Nebula which would be expected from this assumption.

and vice versa.

In [1], we suggested a mechanism for producing radiocarbon in the Earth's atmosphere by the action of γ-quanta, possibly accompanied by flares from supernovae. During interaction with nuclei of the Earth's atmosphere, γ-radiation can form neutrons by the reactions: (γ, n), (γ, 2n), (γ, pn), (γ, αn), etc. Moreover, the secondary particles (p, α) can also form neutrons.

Using the value for cross sections of corresponding photonuclear reactions [30-33], we obtain (for the probability of formation of neutrons by γ-quanta with an energy of 25 MeV) the value $\sim$5% and $\sim$ 2% for $E_\gamma \simeq 50$ MeV.

Even in 1946, Libby [34] was able to show that neutrons, formed in the atmosphere, should be absorbed by interaction with nitrogen, forming radiocarbon by the reaction (n, p). /13

In Table 2, the magnitude of a change in radiocarbon concentration in the Earth's atmosphere after explosions of supernovae in our galaxy are shown for three values of absolute energy of γ-radiation -10^{48}erg, 10^{50}erg, and 10^{52} erg.

The data that we have at the present time on the supernovae in 1054, 1572, 1604, and 1700 indicate that the absolute energy of 10^{48}-10^{49}erg/flare [35,36]. It is considered [36] that the total energy of all cosmic rays is two orders greater than the energy of the relativistic electrons, i.e., 10^{50}-10^{51}erg/flare. However, the upper limit of the total energy of cosmic rays is on the order of the total energy of the explosion, reaching 10^{51}-10^{52}ergs and even 10^{53}-10^{54}erg [15, 19, 37, 38]. If the γ-quanta are generated because of the interaction of relativistic protons with material from the shell of a supernova, then the absolute energy of the γ-component should be of the same order as the energy of the space radiation (in any case, not much less).

In order to evaluate a change in radiocarbon concentration in the Earth's atmosphere, besides the energy of the γ-component we must know the distance from the Earth to the supernova. Unfortunately, the data we have sometimes differ by orders of magnitude. Thus, for example, according to the data of [15, 16, 36, 39], the distances from the Earth to Tycho Brahe's supernova are 360 ps, (1500-1700) ps, 2400 ps, and 3300 ps, respectively. The distance to Kepler's supernova varies from 1000 ps [36] to 9900 ps [39]. Depending on the shape of the Crab Nebula, the distance to it can be 1100 ps (compressed form = two axes equal, and the third less) or 1700 ps (extended form = two axes equal, and the third greater). As for Cassiopeia A, all the authors take the value 3400 ps as the distance to it.

The values for changes in radiocarbon concentrations, shown in Table 2, reflect the inaccuracy in determining distance.

At the present time, the accuracy for recording radiocarbon

TABLE 2. VARIATION OF C^{14} CONCENTRATION IN THE ATMOSPHERE

Source	Energy Radiation MeV	Change in Radiocarbon Conc. in the Atmosphere / % /		
		Total Energy of the γ-Component /erg/		
		10^{48}	10^{50}	10^{52}
Kepler's Supernova (1604)	25	$5\cdot10^{-4}$ to $5\cdot10^{-2}$	$5\cdot10^{-2}$ to 5	5 to 500
	50	10^{-4} to 10^{-2}	10^{-2} to 1	1 to 100
Tycho Brahe's Supernova (1572)	25	10^{-2} to $4\cdot10^{-1}$	1 to 40	10^{2} to $4\cdot10^{3}$
	50	$2\cdot10^{-3}$ to $8\cdot10^{-2}$	$2\cdot10^{-1}$ to 8	20 to 800
Cassiopeia A (1700)	25	$5\cdot10^{-3}$	$5\cdot10^{-1}$	50
	50	10^{-3}	10^{-1}	10
Crab Nebula (1054)	25	/2 to 4 /$\cdot10^{-2}$	2 to 4	200 to 400
	50	/ 4 to 8 /$\cdot10^{-3}$	/ 4 to 8 /$\cdot10^{-1}$	40 to 80

concentrations in tree rings has reached 0.3%, and we may succeed in bringing it to (0.1-0.05)%.

An examination of the data from Table 2 shows that, if the energy of the γ-component is not less than 10^{49}erg, it would seem possible to be able to find during an experiment, a change in the C^{14} concentration in the Earth's atmosphere, caused by a supernova flare. /15

As we have already shown earlier, there are no really reliable estimates of the energy of the γ-component. Only one point is clear: emission of γ-quanta by supernovae in a quantity sufficient for finding reflections of the flares in radiocarbon amounts is actually not eliminated by the present hypothesis. In such a situation, it is necessary in our opinion to determine the C^{14} content in the Earth's atmosphere, during an experiment, with an accuracy which is not worse than (0.3-0.1)% for the years corresponding to the flares of the already well-known supernovae. If the effect proves to be positive, then we can estimate the energy of the γ-component during a supernova flare, which would allow us to a certain extent to choose from among the existing hypotheses on the mechanism of supernova flares. Moreover, we would have the experimental possibility of investigating undiscovered flares.

Establishment of a precise date for the flare of Cassiopeia A is also of significant interest. At the present time, it is considered to have occurred around 1700.

The change in C^{14} percentage in the Earth's atmosphere with times calculated according to (2) for two values, is shown in Figure 2:

$$\frac{1}{\lambda'} = T \simeq T_1 - 6\wedge,\ 30\wedge \text{ and } \nu - 30, 60.$$

Note that the front of concentration increase will not be as abrupt. This is, because (1) the flare process in supernovae is of finite length (Fig. 1), and, secondly, because there are lags in C^{14} dispersion in the Earth's atmosphere. The first reason obviously changes the form of the curves shown in Figure 2 insignificantly, since the principal mass of energy of a supernova is emitted in less than a year. As for the time for dispersion, there is no precise data on this at the present time. In [40], we see that the time for dispersion in the stratosphere is 5 years, and in the troposphere, 1-2 years.

If, during the experiment, we succeed in finding flares from supernovae and in determining the rate of change in the C^{14} concentration in the atmosphere, it might then be possible to determine the characteristic times for C^{14} dispersion in the Earth's atmosphere and its transition to other reservoirs. /16

IV. Solar Activity and Radiocarbon

It has been reliably established that the intensity of the primary cosmic rays which reach the Earth depends on the condition of the Sun. Absolute intensity of cosmic rays varies greatly during an 11 year cycle of solar activity. These variations are connected with the conditions for movement of cosmic rays in interplanetary space, and are basically related to low-energy particles. Thus, for example, the intensity of protons with an energy of 100 MeV varies from the minimum of solar activity (1953-1954, and 1965) to the maximum (1958) by a factor of 4; for protons with E = 2.5 Bev, it varies by not more than 40%.

The rate of formation of neutrons (and hence the rate of formation of C^{14} in the Earth's atmosphere) vary with a change in the flux of primary cosmic rays.

In [41], the question of the change of the rate of radiocarbon formation from the minimum of solar activity (1953-1954) to the maximum (1957-1958) is examined in detail.

The principal results of [41] are shown in Table 3.

If we assume a linear relationship between the number of sunspots and the rate of formation (q) of C^{14}, we can obtain the following equation:

$$q = 2{,}61 - \frac{0{,}53(S-9{,}1)}{178{,}4},$$

where S is the average annual number of sunspots -(1953-1954, S = 9.1; 1957-1958, S = 187.5). Then, for the average rate of C^{14} formation in the last 111 years, we obtain the value 2.50±0.50 atoms $cm^{-2}sec^{-1}$ [41]. We also should note that the formation of C^{14} by the action of neutrons which are produced as a result of the interaction of protons of a solar flare with nuclei of the atmosphere, was not included in these estimates. Actually, the average rate /17
of C^{14} formation in many periods of solar activity will be greater than 2.5 $cm^{-2}sec^{-1}$. [8]

On the other hand, the rate of decay of C^{14} is 1.8±0.2 [12] and 1.9±0.2 [42] in the same units.

We have the impression that, in the last 100 years, the rate

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[8] Note that the rate of C^{14} formation at the maximum of solar activity will decrease because of a decrease in the intensity of the primary cosmic rays, and will increase because of nuclear reactions under the influence of protons from a solar flare. According to Stuiver [43], the effect of protons from a flare must be small.

of C^{14} formation was greater than the rate of decay, i.e. there must have been an increase in the radiocarbon concentration in the Earth's atmosphere.

TABLE 3. RATE OF FORMATION OF C^{14} ATOMS cm^{-2} sec^{-1}

Geomagnetic Latitude	Rate of Formation of C^{14}	
	1953-1954	1957-1958
0	0,98	0,93
10	1,01	0,96
20	1,22	1,15
30	1,83	1,63
40	3,02	2,45
50	4,52	3,44
60	5,26	3,79
70-90	5,38	3,79
Average	2,61	2,08

We should also note that the reliability of the calculated values for the rate of C^{14} formation (Table 3) is low (error $\sim 20\%$), i.e. the error spans the difference between the values 2.6 and 2.08. However, this circumstance cannot obscure the experimental fact of a change in the flux of neutrons and, thus, of the rate of C^{14} formation from the minimum to the maximum activity. We should consider the values written above as tentative ones which require precise experimental verification. /18

Thus we can conclude that there are indications of a change in the rate of C^{14} formation by 20% from the maximum to the minimum of solar activity, and also a monotonic increase of the same magnitude in a period of about 100 years.

Formula (3) indicates a possibility of estimating the amplitude of the change in the percentage of radiocarbon in the Earth's atmosphere. The dependence of the function F_1 on the period of change in the rate of C^{14} formation is shown in Figure 3. As we can see from the figure, the attenuation factor for a period of 10 years is $\sim 10^{-2}$, and for 100 years, it is $\sim 10^{-1}$. In other words, if in an 11-year cycle of solar activity, the rate of formation of C^{14} varies by 20%, then the amplitude of the change in concentration is 0.2%. During a period of 100 years, the change in concentration is $\sim 2\%$.

Thus we come to the conclusion that, in order to study the nature of solar activity in the past, we must measure the concentration of radiocarbon in dendrochronologically dated samples with a high accuracy (not worse than 0.2-1%).

V. Experimental Possibilities

A complete cycle of experimental research includes the following stages:

(1). Obtaining dendrochronologically dated samples in the necessary quantities.

(2). Determining the concentrations of radiocarbon in the samples.

(3). Determining the radiocarbon content in the Earth's atmosphere according to the experimental value for its concentration in samples with known age.

We will consider all the stages briefly in turn.

(1) DENDROCHRONOLOGY

Dendrochronology is the method of dating woody plants by their annual rings. Usually, only one ring is formed in one growing /19 season. The width of the annual ring depends on many factors[9]: the life of the plant, the position of the layer in the trunk, the rate and amount of fruit bearing, the meteorological conditions, the shade of other trees, forest fires, etc. [44]. The large quantity of variable factors, whose concrete effect on the ring's width is unknown, leads us to the conclusion that there is no sense in making a comparison of the widths of the rings in one and the same year for two different trees. We could obtain some substantial conclusions only by comparing the rings in different years for one and the same tree. Since the action of a series of factors is identical in significant areas, the dynamics of the growth of rings will be identical for various trees which are growing at the same time, not far from each other. This condition is essential for relative dating of various trees. If we succeed in finding out the absolute age of any tree, then it seems possible that we could establish an absolute dendrochronological scale. Such a scale would provide for determining the age of wood with an accuracy up to 1 year. A. Douglass (1935) first succeeded in establishing an absolute scale from the year 698 to 1929 for the southwestern regions of the USA [45].

In the USSR, an absolute scale was first established by B.A.

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[9]Even in the 15th century, Leonardo da Vinci noticed that a series of narrow and wide annual rings in trees corresponded to an alternation of wet and dry years.

Kolchin, for material in Novgorod (wooden bridges, drainage systems, lower logs of buildings). The length of the entire scale includes 578 years - from 884 to 1462 [44]. Kolchin's absolute scale was made up for pines growing in productive types of forest, and naturally we could never determine the age of just any type of wood on this scale [45].

Thus, in order to determine the precise date of growth of any ring, we must have the absolute dendroscale for a given type of tree and the place where it grew.

The task is relatively simple for trees growing at the present time. But even here there are some difficulties: we know that there are years when several rings grow at once, or when there are no rings at all. Undoubtedly, in this case, we must establish a dendroscale on the basis of measurements of the width of the rings for many trees of a given type and in a given region.

In radiocarbon measurements, there is an added difficulty /20
caused by the necessity of obtaining wood from one annual ring in large quantity. Thus, for example, in order to determine the radiocarbon content with an accuracy to (0.2-0.3)%, we must have wood in an amount of several hundred grams for the scintillation method of measuring C^{14}. If we have a goal of measuring the content with an accuracy of (0.02-0.03)%, then we need 100 times more wood, i.e., tens of kg.

Thus we see that, in the course of realizing our ideas on the role of radiocarbon in astrophysical research, there are serious difficulties involved. Our position is made worse by the fact that there is only one laboratory of dendrochronology in the USSR- in the Archeology Institute of the Academy of Sciences of the USSR. We find a rapid increase in research on dendrochronology necessary, not only because it is necessary to date the rings precisely, but also because this area of science is of great independent scientific and practical interest.

2. DETERMINING THE C^{14} CONCENTRATION IN THE SAMPLES

In order to determine the radiocarbon concentration in the samples, proportional and scintillation measuring devices are used. At the present time, equipment is being developed which allows for determining C^{14} concentration with an accuracy up to 0.3%. The accuracy of this determination is limited by the background and stability of the equipment, and by the quantity of radiocarbon. The latter limitation, in turn, depends on the age of the sample and on the quantity of wood. We can succeed in determining ages up to 50,000 years. A further increase in the limit of age determination is made substantially difficult by the necessity for a greater quantity of wood. Actually, for 100% measurement efficiency and for a measuring time of 10^6sec, achievement of accuracy to 1% requires 1 g. of present day wood. In order to measure an age of

50,000 years, we need 1 kg., and for 100,000 years, we need 1 ton. Moreover, the limited size of the detector necessitates an isotopic enrichment of C^{14} relative to C^{12} and C^{13}. Under other variable conditions, and with a sufficient quantity of wood, an increase in the age limit calls for an increase in enrichment by a factor of a thousand every 50,000 years. Therefore, if we had even a hundred tons of old wood, there would be a limit to measuring the age because of the difficulty of isotopic enrichment.[10]

We would like to say something about the accuracy of dating has an accuracy of $\sim 1\%$. It is not determined by statistics alone. Even if the statistical error and the background of the calculating apparatus are zero, it is doubtful that we would succeed in measuring with a greater accuracy than 1%. The point is that the radiocarbon concentration in the Earth's atmosphere varies with time, while the amplitude of oscillations in the past achieved several percent. At the same time, in determining the age, it is assumed that the radiocarbon content during the time of the tree's growth was the same as now.

After the relation of C^{14} concentration to time has been measured with great accuracy, we will be able to measure the age of the sample (in principle) with an accuracy up to 1 year, not by the average activity of the sample, but according to a graph of the annual variations. As for measuring the C^{14} content in dendrochronologically dated samples, besides the difficulty in obtaining a large quantity of wood, there are substantial difficulties with the stability of the experimental apparatus. For an accuracy of 0.01%, the total number of recorded β-particles from C^{14} should be 10^8, which, at a rate of $10^2/\text{sec}^{-1}$, calls for measuring times of $\sim$ 10 days.[11] For such a time, we must guarantee stability in the effectiveness of the calculations with an accuracy which is not worse than 0.01%. In existing instruments, the β-particles are measured in an energy window set by two threshold potentials. At a high rate of calculation, the background of the instrument in the high-energy range is not extreme, and therefore the upper threshold can be set at a point higher than the limit of the β-spectrum, thus reducing the necessity for its stability. The problem is worse for the lower threshold, which depends on noise pulses. In this case, we must use a special system of forced stabilization.

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[10] In working with old samples, there are obviously other difficulties also, such as the danger of contamination by present day carbon.

[11] It is not easy to achieve such a rate.

3. DETERMINATION OF THE RADIOCARBON CONTENT IN THE EARTH'S ATMOSPHERE /22

We will briefly examine those difficulties which crop up in determining the radiocarbon content in the Earth's atmosphere according to the experimental values for C^{14} concentration in the rings of trees.

First of all, we must clarify the problem: are there not migrations of radiocarbon from ring to ring? In a number of laboratories, special experiments were conducted which were dedicated to a study of the C^{14} content in rings of living trees before and after a period of experimentation with nuclear bombs. It is well known that the C^{14} content in the atmosphere increased by a factor of more than 2 because of nuclear bombs. The measurements showed that there is no migration from the outer to the inner layers, with an accuracy up to fractions of a percent.

It was established that plants assimilate C^{12} more readily than the heavier C^{13} and the even heavier C^{14}. On the other hand, the exchange mechanism between the carbon dioxide of the atmosphere and the carbonate of the hydrosphere causes a great concentration of C^{14} in carbonates. The qualitative results were obtained from measurements of C^{13} concentrations on a mass spectrometer, considering the coefficient of the enrichment factor of C^{14} twice that for C^{13}. As a result, it was seen that the C^{14} concentration in carbonates was 1.2% greater than in the atmosphere, and 3.7% less in plants. The principal consideration here, however, lies in the fact that these values are a function of the local conditions for the tree's growth, which implies the necessity of measuring the C^{12}/C^{13} ratio for each sample, especially if we are concerned with accuracies which are better than 1%.

As for the relationship of the radiocarbon concentration to the latitude of the locale, recent research [46] has shown (with an accuracy to several tenths of a percent) that the radiocarbon concentration in the ring is not a function of the latitude.

VI. Examination of Available Experimental Data /23

In the last two years, studies [8-11, 47, 48] have appeared in which experimental values for radiocarbon concentration in samples with a known age have been presented for a long range of time, from the present to 1000 B.C. (Figures 4-8). The data shown in the figures indicate that the radiocarbon concentration in the Earth's atmosphere did not remain constant in the last 3000 years. We obviously have pronounced minima and maxima. Pronounced maxima are clearly evident around the years 1500 and 1700, and a minimum around 1600. These peaks were also observed earlier in other studies [6, 7]. There is a faint possibility that there were maxima around the year 700, and around 380 (Figures 4, 6).

As we go further back in time, the radiocarbon concentration decreases monotonically, reaching a minimum around the year 1, then increases up to the year 1000.

Thus, with a variation of the C^{14} concentration in the atmosphere, we can obviously select variations with characteristic times of 2000 years and 200 years.

In [49] tables of the dependence of the Wolf numbers on time are shown for the period from 649 B.C. to the present. These curves were constructed on the basis of an analysis of the available data according to the variations of the Wolf numbers with time and of information on earthquakes, aurorae, and other natural phenomena. In this paper, we cannot discuss the question of the reliability of the values for the Wolf numbers which are presented in that paper. We will only note that systematic studies of the spots on the Sun have been made since the middle of the 18th century and therefore the values for the Wolf numbers for earlier periods are calculated from limited assumptions which require experimental verification. The relation of the Wolf numbers to time for the last 1000 years according to the data of [49] are shown in Figure 9.

A comparison of Figure 9 with Figures 7 and 8 shows that the maxima of radiocarbon content in the Earth's atmosphere around the years 1500 and 1700 coincide with the minima of the curves showing the Wolf numbers as a function of time. Such a coincidence implies the possibility of assuming that the 200-year variations in radio- /24
carbon concentration in the Earth's atmosphere are caused by the activity of the Sun. Then, on the basis of the data in Figure 3, a change in C^{14} content by 2% may have been caused by a variation in the rate of radiocarbon production if it is $\sim 40\%$. We can obtain such a change in the rate of C^{14} production if we consider the relationship between the Wolf number and the rate of radiocarbon production as linear.

Thus we come to the conclusion that the experimental data on the C^{14} variation in the Earth's atmosphere for the last 400-500 years do not contradict the assumption of the presence of a correlation between the Wolf numbers and radiocarbon concentrations. Naturally, there are some unclear points. In particular, why is the 200-year cycle clearly pronounced only for the last 400-500 years? One thing is clear: if there is a 200-year cycle in earlier periods, its amplitude does not exceed 1% (Figures 4-8). This means that, if there is a 200-year cycle in solar activity, then its characteristics do not vary with time. More detailed and accurate measurements of the radiocarbon content in the Earth's atmosphere perhaps will reliably show the existence of a 200-year cycle, and (very important) will allow a determination of its characteristics in the past.

The experimental data which we have, do not allow us to draw any basic conclusions regarding the 78-year cycle of solar activity proposed in [49].

What conclusions can we draw regarding the effect of supernova flares? We will immediately note that there are not now any detailed studies for the years around the time of supernova flares. However, we can still reach some conclusions from the data we have. We will examine all the flares in sequence.

The Supernova in the Crab Nebula (1054)

The C^{14} content was experimentally determined in samples from the following years: 1023±3, 1067±7, 1096±4, [8]; 1003±11, 1052±10, 1100±8 [9]; 956±10, 1056±10, 1136±10 [10]; 1009±25, 1109±25 [7]. The length of the interval of time from which the rings were taken is indicated, and not the error in determining the age of the sample.

The only conclusion which can be reached in comparing the data of Figures 4-8 with Table 2 is that, obviously, the total energy of the γ-radiation of the supernova in the Crab Nebula was less than 10^{52} erg.

Tycho Brahe's Supernova (1572) /25

The C^{14} concentration was determined in samples for the following years: 1537±2, 1563±1, 1582±2, [8]; 1450±10, 1505±13, 1597±5 [9]; 1516±10, 1596±10, 1656±10 [10]; 1509±25, 1579±25, 1609±25 [7]. In this case, with the same caution as for the Crab Nebula, we can only conclude that the total energy of the γ-component is hardly greater than 10^{51} erg.

Kepler's Supernova (1604)

The C^{14} content in the samples was determined for the following years: 1582±2, 1597±2, 1605±5, 1622±2 [8]; 1597±5, 1646±4, [9]; 1596±10, 1657±10 [10]; 1559±25, 1609±25, 1659±25 [7]. A comparison of the data from Table 2 with Figures 4-8 provides a possibility of estimating the upper limit for the total energy of the γ-component. It is equal to 10^{52} erg.

The Supernova of Cassiopeia A (~1700)

The C^{14} content was determined experimentally for samples from the following years: 1695±5, 1710±10, 1712±2 [8]; 1646±4, 1697±5, 1829±13 [9]; 1676±10, 1696±10, 1650±10 [10]; 1659±25, 1709±25, 1759±25 [7].

As we already noted, around 1700 there is a peak in the radiocarbon content in the Earth's atmosphere in all the studies. This peak could be caused by the cyclic solar activity. Detailed yearly studies around 1700 are also lacking. Therefore, we can only note that the total energy of the γ-component at the time of the supernova flare from Cassiopeia A was hardly greater than 10^{52} erg.

Thus we come to the conclusion that, at the present time, there are no detailed studies for the years which correspond to supernova flares. Therefore, we are not in any position to make statements regarding the presence or absence of correlations between supernova flares and the C^{14} concentration in the Earth's atmosphere. We can only maintain that neither experimental data nor theoretical notions can deny the presence of such a correlation.

As we have already noted, the C^{14} concentration in the Earth's atmosphere decreases monotonically as we go further back in time, and reaches a minimum around the year 1; it then increases up to 1000 B.C. The cause for such a change is not clear at the present time. Such a variation in the past could be caused by a change in the magnetic field of the Earth with time. It is well known that the intensity of cosmic rays striking the Earth's atmosphere decreases with an increase in the magnetic field of the Earth. From /26 the experimental data which we have on the thermoremanent magnetization of burnt clay [50], it follows that the intensity of the Earth's magnetic field increased from the year 1, attained values of 1.4 H_0 (H_0 is the intensity of the field at the present time), and then began to decrease, i.e. the maximum of the Earth's magnetic field coincides with the minimum of C^{14} content in the Earth's atmosphere. This fact allowed the authors of [10] to conclude that the 2000-year cycle in the relationship of the C^{14} concentration to time is caused by a change in the Earth's magnetic field.

In addition to the causes mentioned earlier, the variations in radiocarbon content in the Earth's atmosphere may also be caused by a change in the rates of dispersion among various reservoirs, caused by climatic changes in the past, by volcanic activity, etc.

A hypothesis has been proposed according to which a change in C^{14} concentration can take place during an entry of antibodies into the Earth's atmosphere. As an example, the antimaterial nature of the Tungus meteorite was shown in [47]. In connection with the great interest in the problem of antimatter, it is considered expedient to examine in relatively greater detail, the results of works studying the C^{14} content around the year 1908 - the year of the fall of the Tungus meteorite.

The Tungus meteorite burst into the atmosphere at a height of 5-10 km, on June 30, 1908, at 12:17 a.m. universal time (around 7:00 a.m. local time) in Siberia in the region of the Podkamennaya Tunguska River. According to various estimates, the energy of the explosion reached 10^{23}-10^{24}erg. Our problem does not concern an examination of various hypotheses on the nature of the Tungus meteorite. We would like only to examine the hypothesis on the antimaterial nature of the Tungus meteorite. We will assume that the Tungus catastrophe was due to the entry of an antimeteor into the Earth's atmosphere. Then, because of annihilation, neutrons must have been formed, which, according to the reaction (n, p) in nitrogen, produce C^{14}. An analysis shows that, for every antinucleon annihilated, 2-3 neutrons are formed, not 8±4, as Cowan, Atluri, and Libby stated [47]. Then, with the total energy of the Tungus body equal to 10^{24} erg, the total number of C^{14} nuclei produced should be $(6\text{-}10)\cdot 10^{26}$, i.e. the change in the C^{14} content is 2-3%. If we take the minimum estimate for the energy of the Tungus body as 10^{23}erg, we obtain an increase of (0.2-0.3)%. Cowan, Libby, and Atluri determined the C^{14} concentration in the annual layers of wood (oak and spruce from the state of Arizona) from 1870 to 1936, with an accuracy of 0.3%. The results they obtained are shown in Figure 10. As we can see from the data presented, the activity of C^{14} in 1909 increased by 1% in comparison with the years 1908 and 1910. This increase is within the range of measurement error and we can therefore conclude that a confirmation of the antimatter hypothesis is, in any case, risky. /27

At the Institute imeni Vernadskiy, studies were conducted [48] to determine the C^{14} content in the annual rings of a tree from the region where the Tungus body exploded. The results of the studies are shown in a figure in [47]. An 140-year-old larch, which was felled in the autumn of 1961, served as the object of the study. The vegetative period for that type of tree lasts from the end of May to the middle of September, and, therefore, we should expect an increase in C^{14} in the ring of 1908. As we can see from the data obtained (Fig. 10), the content in the 1908 rings was greater than for 1909 and 1910. It would seem that the presence of a connection between the Tungus catastrophe and the C^{14} content in the Earth's atmosphere is substantiated. However, as in [47], the measurement error exceeds the difference between concentrations for the years 1908, 1909, and 1910. Therefore, in our opinion, the single conclusion which we can make from the data obtained in [47, 48] is that the experimental data on C^{14} do not exclude the possibility of an antimaterial nature for the Tungus body.

Another substantial objection to the idea of an antimaterial nature for the Tungus body is that the probability of an antibody penetrating into the atmosphere to such a great depth is very low.

Venkatavaradan [51] considers that the change in the C^{14} content in the Earth's atmosphere around 1908 was caused by cyclic solar activity. In 1909, we find one of the minima for solar activity, and this could correspond in principle to the increase in C^{14}. However, we will note that a comparison of the relationship /28 of the numbers of spots (Fig. 11) to time, with the data of Figure 10, shows that the minimum and maximum in Figure 10 do not necessarily correspond with the minimum and maximum of Figure 11. Thus, we cannot consider the question of the connection of the C^{14} content with the Tungus catastrophe to have been solved. Further investigations are necessary.

VII. Brief Conclusions

I. The question of the possibility of studying various astrophysical phenomena (the cyclic activity of the Sun, flares from supernovae, etc.) by determining the radiocarbon content in dendrochronologically dated samples was examined.

II. It was shown that flares from supernovae can coincide with an increase of the C^{14} concentration in the Earth's atmosphere to a value which can be recorded, if, at the time of the flares, γ- quanta are emitted with a total energy which is not much less than the energy of cosmic rays.

If a correlation between flares from supernovae and the radiocarbon concentration in the Earth's atmosphere is found during the experiment, it then becomes possible to obtain information on the characteristics of the flares and, in particular, to determine the total energy of the γ-component.

A knowledge of the behavior of the C^{14} concentration with time in the Earth's atmosphere permits a determination of the characteristic times for dispersion into various reservoirs. Moreover, it becomes possible to determine the dates for flares which have not yet been discovered and to determine their characteristics.

III. Detailed studies of the C^{14} content in the Earth's atmosphere for a long interval of time in the past permit determination of the state of solar activity in various years in the past, and clarification of the principles of the activity of the Sun.

IV. In order to fulfill the complex program for "Astrophysical Phenomena and Radiocarbon", the following are necessary: /29

(1) Development of the dendrochronological method of determining the age of wood for a broad range of time from the present to several thousand years B.C. and more.

(2) Development of methods for determining the C^{14} concentration with an accuracy of (0.3-0.1)%. In this case, we must pay special attention to the problem of the stability of the experimental apparatus and the reproducibility of the results.

In order to improve the basic parameters (accuracy, stability, reproducibility) of current methods for recording C^{14} (proportional and scintillation recorders) we must go beyond the obvious methods (decrease in the background, increase in the size of the detector, application of stabilization systems) to develop methods for enrichment of C^{14} relative to C^{12} and C^{13}. Thus, for example, enrichment by a factor of 100 (all else being equal) results in a ten-fold increase in the statistical accuracy. On the other hand, with exactly the same statistical accuracy, work with enriched carbon requires less time, and, correspondingly, produces more stable and reproducible results.

In a number of cases, particularly when working with very old samples, the quantity of carbon will be limited. In this case, a mass-spectrometric method of determining the quantity of C^{14} atoms may be more promising. The sensitivity of the mass-spectrometric method can reach 10^{10} atoms of C^{14} (a gain, in comparison with existing methods, by a factor of 30) [52]. The production of highly-sensitive mass-spectrometers and an enrichment of C^{14} relative to C^{12} and C^{13} can ensure an increase in the age limit accessible for measurement.

(3) Development of a qualitative mechanism for the connection between astrophysical phenomena and the radiocarbon content in the Earth's atmosphere.

V. We admit that realizing the complete program for studies of the problem of "Astrophysical Phenomena and Radiocarbon" involves serious difficulties. Despite this fact, we find it necessary to conduct such studies, since they entail (besides the considerations mentioned above):

(a) A sharp increase in the level of dendrochronological studies in the USSR.

(b) An improvement of the basic parameters (accuracy, repro- /30
ducibility) of the existing methods for recording C^{14} atoms; this permits the traditional radiocarbon dating measurements of the samples to be conducted with great accuracy and reliability in a shorter period of time.

(c) An increase in the range of measurements of the age of the samples up to 100,000 years.

VI. A knowledge of the annual variations of C^{14} in the Earth's atmosphere permits dating archeological wood (in principle, to within 1 year), not according to its average activity, but according to the curve of the annual variations.

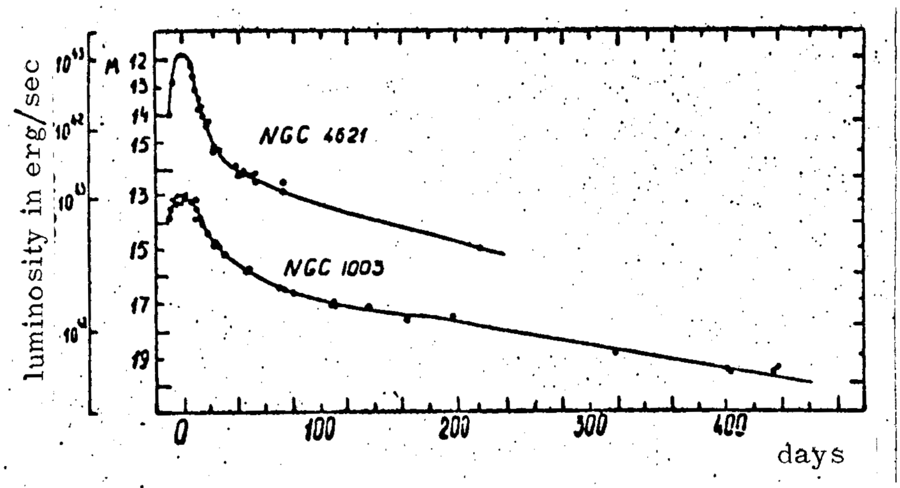

Fig. 1. Luminosity of Supernovae of the First Type versus Time. /31

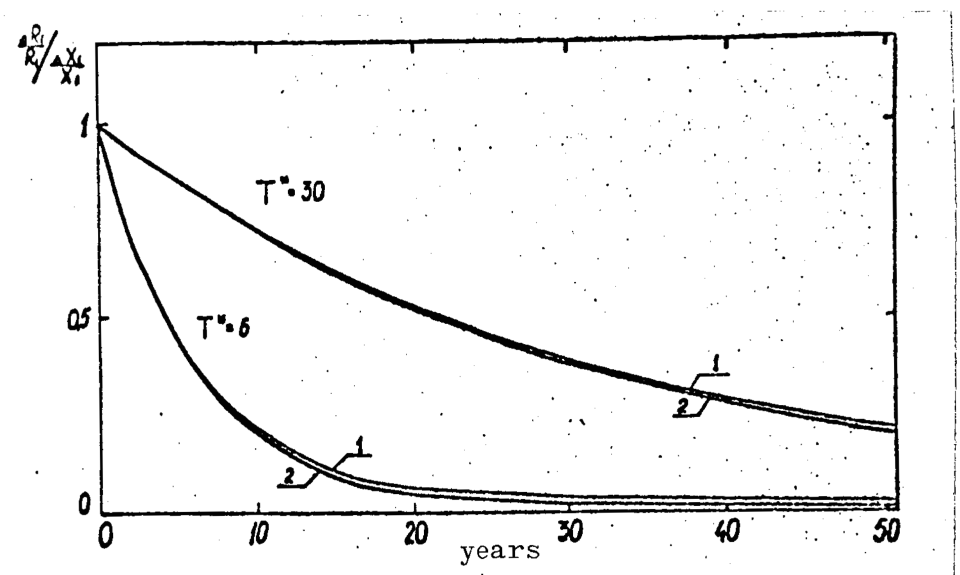

Fig. 2. Change in C^{14} Concentration in the Earth's Atmosphere after a Flare from a Supernova: (1)ν = 30, (2) ν = 60. /32

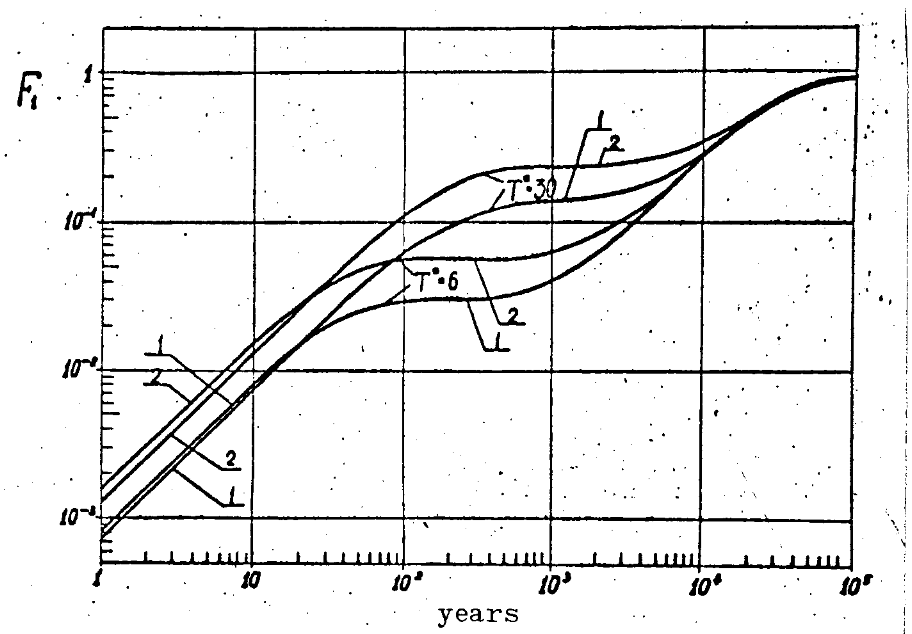

Fig. 3. Function F_1 versus the Period of Change in the Rate of /33
C^{14} Production: (1) ν = 30, (2) ν = 60.

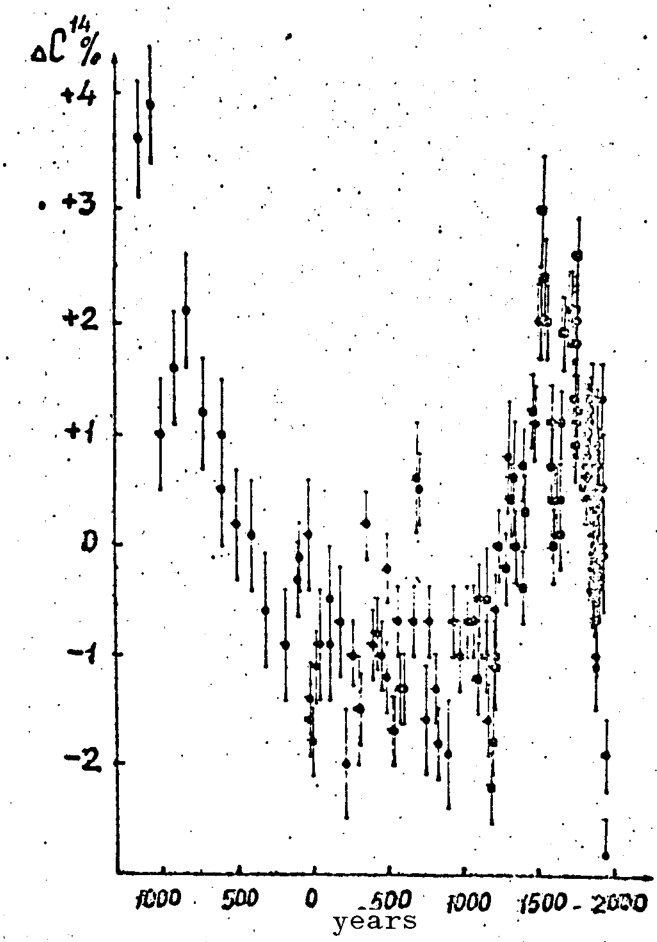

Fig. 4. Variations of Radiocarbon Concentration in the Earth's Atmosphere for the Last 3000 Years, according to Suess' Data [8].

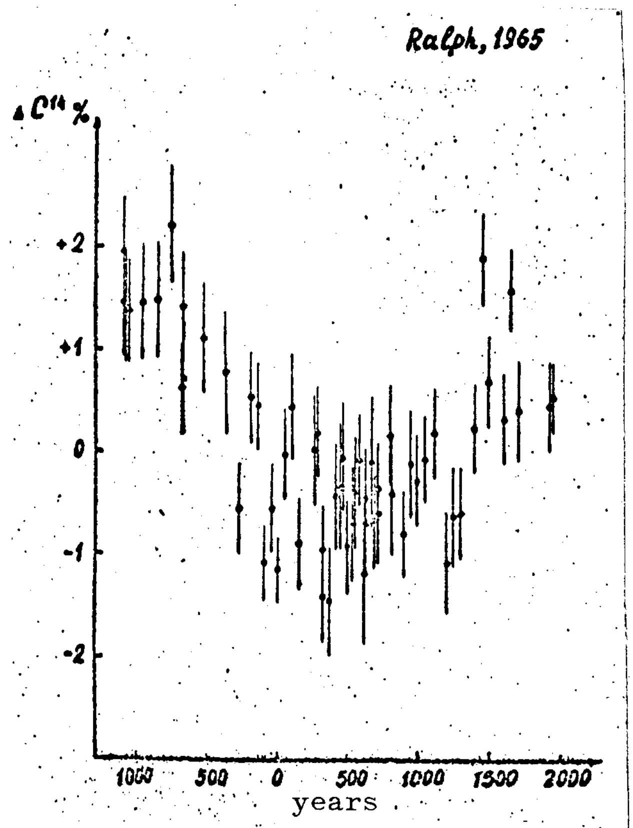

Fig. 5. Variations in Radiocarbon Concentration in the Earth's Atmosphere for the Last 3000 Years, according to the Data in [9]. /35

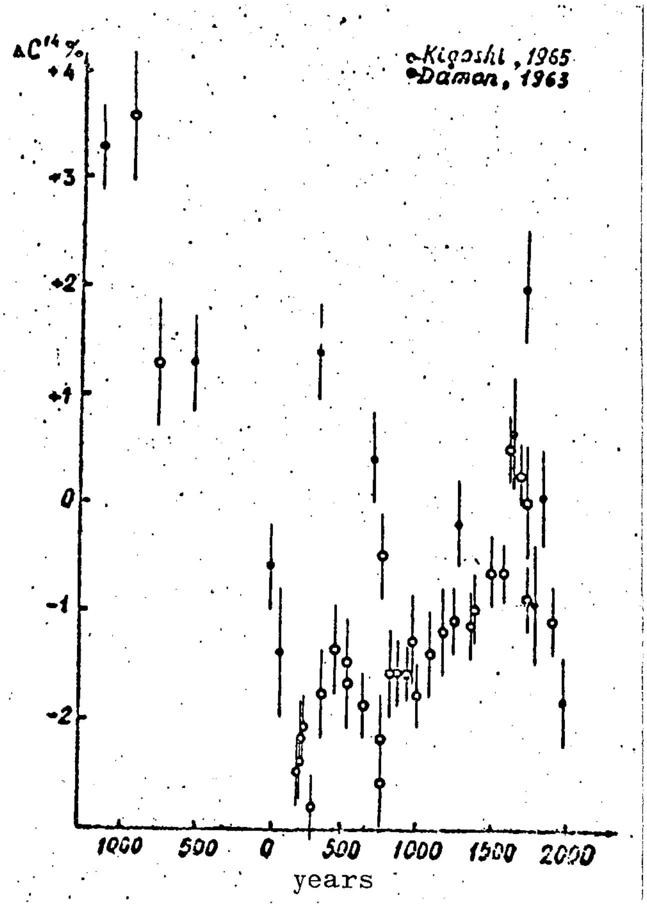

Fig. 6. Variations in C^{14} Concentration in the Earth's Atmosphere for the Last 3000 Years, according to the Data in [10] (circles) and [11] (dots). /36

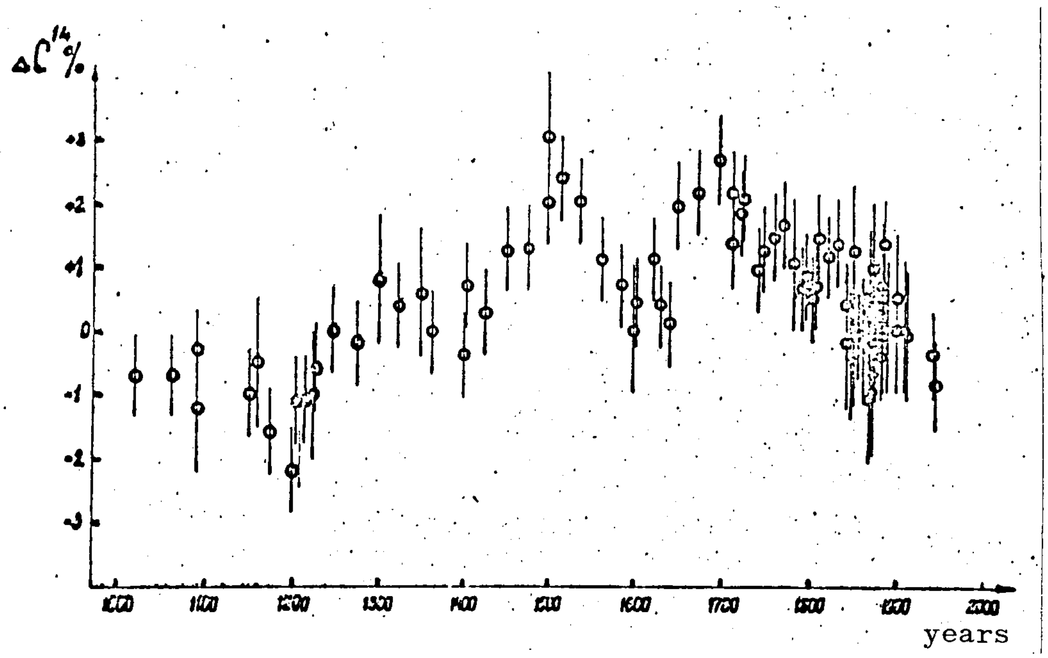

Fig. 7. Variations in C^{14} Concentration in the Earth's Atmosphere for the Last 1000 Years, according to the Data in [8]. /37

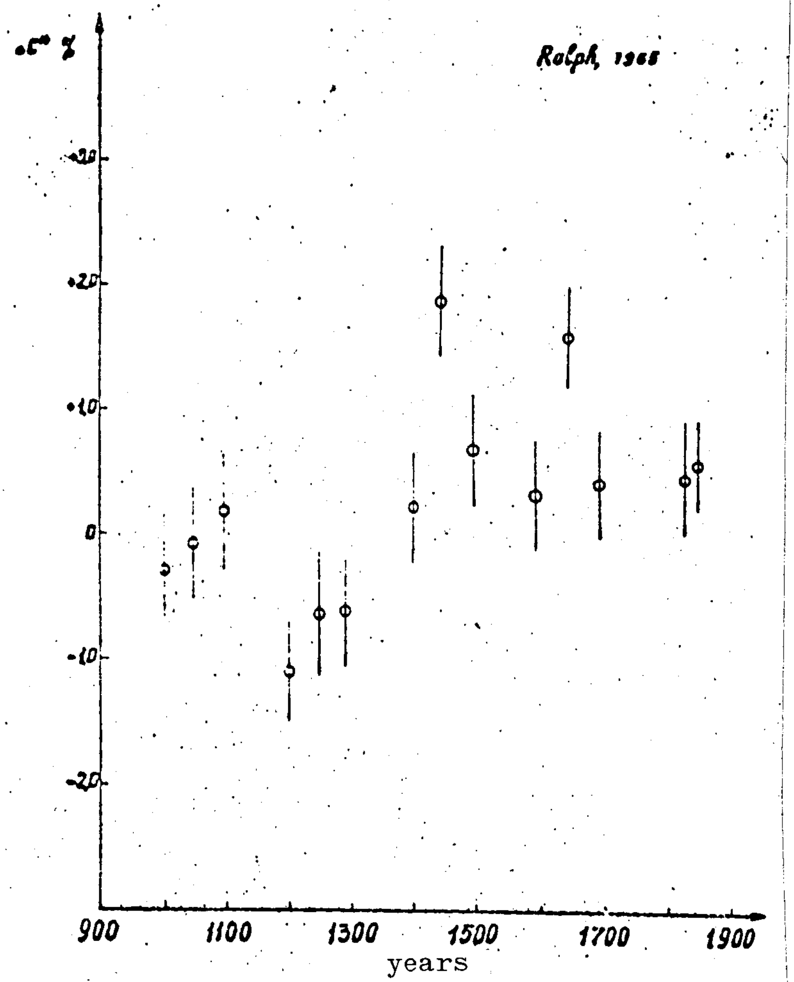

Fig. 8. Variations in C^{14} Concentration in the Earth's Atmosphere for the Last 1000 Years, according to the Data in [9]. /38

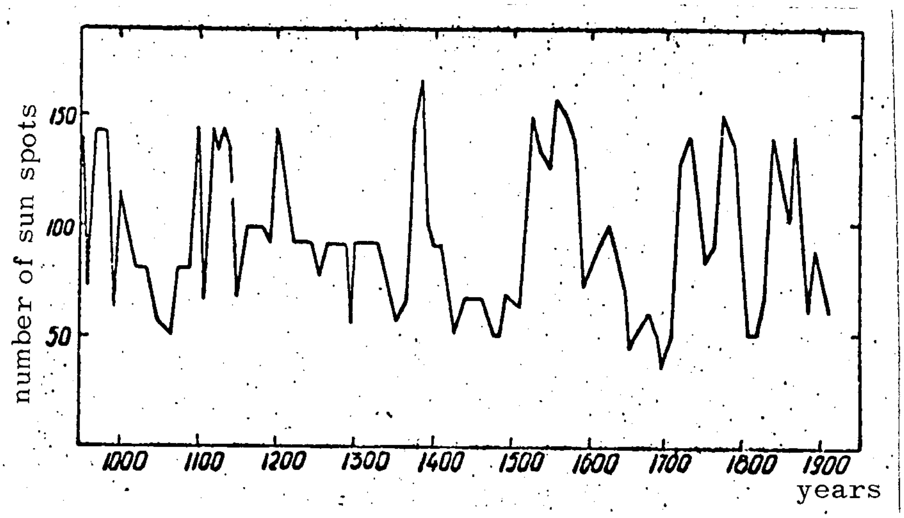

Fig. 9. Number of Sunspots versus Time [49]. /39

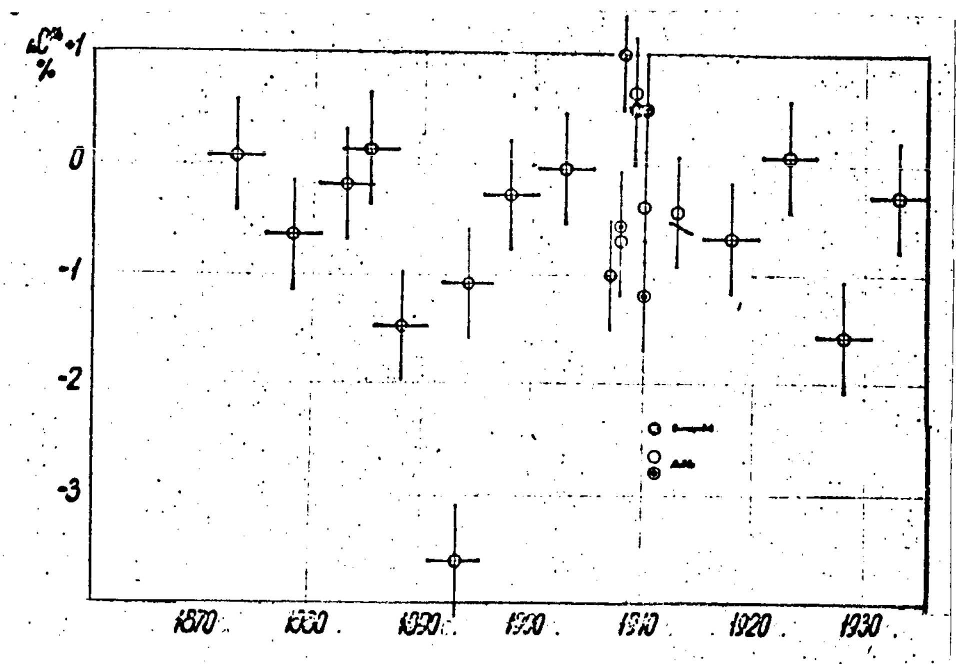

Fig. 10. C^{14} Concentration in Dendrochronologically Dated Tree Rings: ● - according to the data in [48], ○ ⊙ - according to the data in [47]. /40

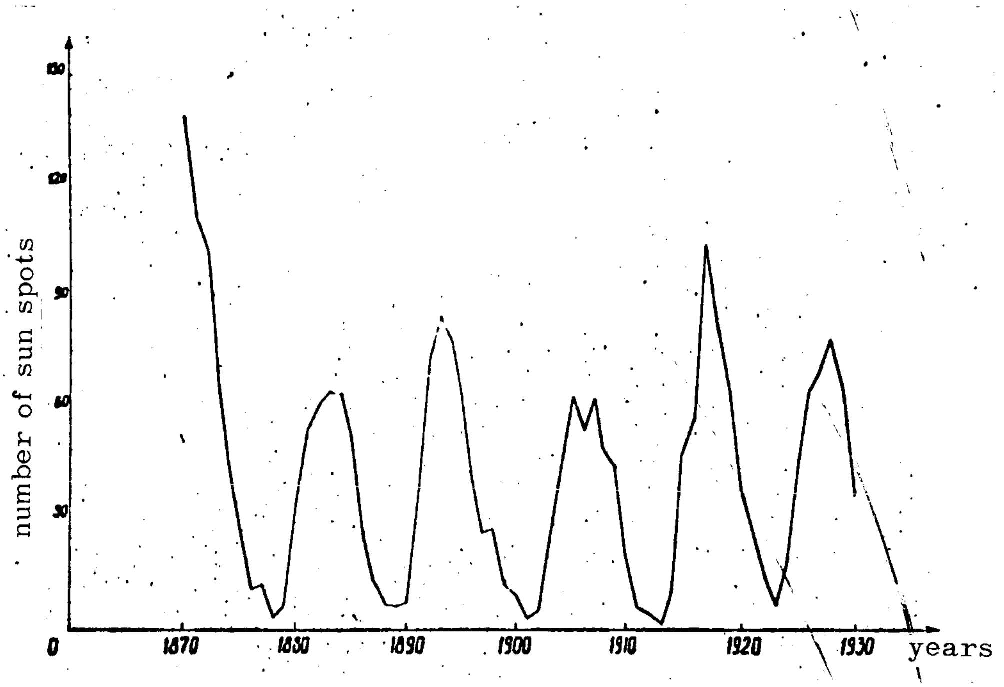

Fig. 11. Number of Sunspots versus Time [49]. /41

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